Effect of Curling on International Roughness Index of Jointed Concrete Pavements.

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ABSTRACT
Roughness is a principal factor that estimates performance and serviceability of the pavements. Slab curvature shape and size change due to curling exert a profound influence on the internal stress and roughness of the pavement, affecting structural and functional performance of the pavement. Therefore, IRI values which measured at identical section are shown differently as measured time changes because variations of temperature and humidity cause the curling and warping of the slab. Effect of curling in slab is responsible for different IRI by measurement time. This can become cause of the wrong judgment when decide rehabilitation at management of concrete pavements. Therefore, need consideration about curling. This study estimate a evaluation of IRI without the curling effect in jointed concrete pavement at any given time by applying Power Spectrum Density Analysis and Inverse Fast Fourier Transformation to the profile data, that can be easily obtained at the construction field site.

1. INTRODUCTION

Joined concrete pavement slabs become curved as a result of differences in the temperature and humidity between the surface and the ground-concrete interface. During the night, when the atmospheric temperature is lower than the temperature on the bottom side of the slab, tensile deformation occurs at the bottom of the slab, while compressive deformation occurs at the top of the slab. This causes upward curling of the slab (Figure 1(a)). Figure 1(b) illustrates the opposite case, when the temperature of the slab surface is higher than that of the slab bottom, a condition that typically occurs during the day.

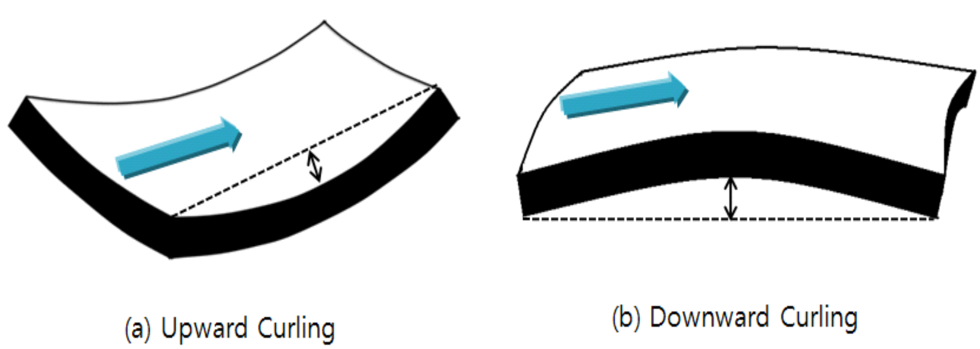

Figure 1 Upward Curling and Downward Curling

Surface profile data of concrete pavement may be considered as a sum of various waves with different

amplitudes and periods. From the combination of various waves, a particular wavelength range that corresponds to a uniform joint spacing can be extracted by the Slab Curling Extraction Method. Therefore, the curling shape of the slab at any given time can be measured if the wave, which has a particular wavelength that corresponds to the slab length (the joint spacing) of the jointed concrete pavement, can be extracted from the profile data. The influence of curling on the roughness can be detected by evaluating differences in the slab deflection at different measurement times. According to the measurement time, the different roughness indices are estimated. Furthermore, the curling measurement is complex and difficult to measure, and a roughness estimate that considers curling is difficult. The shape and magnitude of the curling can vary during a single day. Therefore, the measurement of roughness for a given jointed concrete pavement section may change with the time at which the measurement is obtained. The effects of curling need to be eliminated in the evaluation of International Roughness Index(IRI) in order to obtain consistent measurements for IRI.

2. INFLUENCE OF CURLING ON ROUGHNESS

Pavement roughness is one of the most important performance measures for pavement surface performance conditions. Roughness has been used as a criterion for accepting new pavement construction, and also as a performance measure to quantify the surface performance of existing pavement in pavement management systems at both the network and project levels. The filter of IRI is based on a mathematical model called the quarter-car. The quarter-car filter calculates the suspension deflection of a simulated mechanical system with a response similar to that of a quarter car, as illustrated in Figure 2.

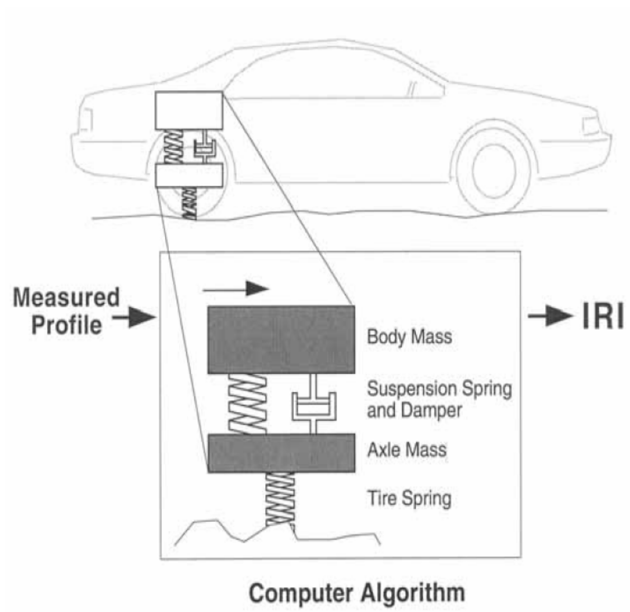

Figure 2 Quarter-Car Model(Sayer,1996)

The smoothed profile is filtered using the quarter-car simulation with specific parameter values(golden car) at a simulated speed of 80 km/hr. It was developed in a 1982 study performed to establish a correlation and calibration standard for roughness measurements. The International Roughness Index has been widely used in many pavement roughness-measuring systems. The curvature shape of the slab changes due to differences in temperature and humidity in the morning and afternoon even during the same day, on the neutral axis at the center of the slab of jointed concrete pavement formed during the early stage of construction, as illustrated in Figure 3.

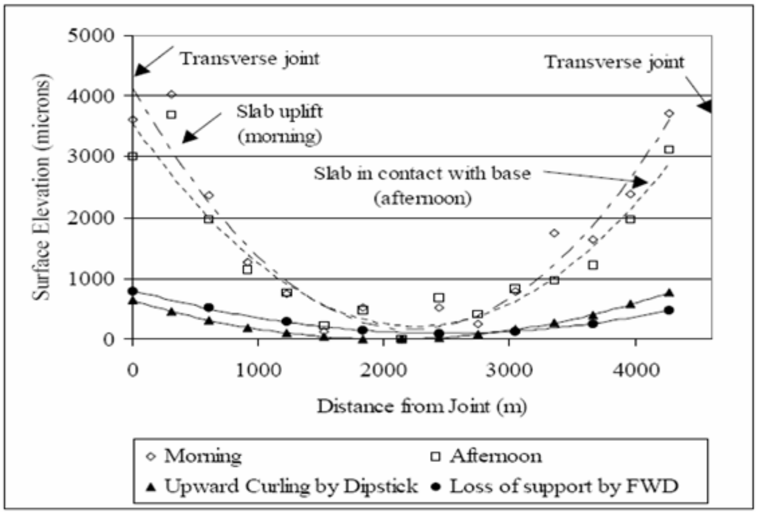

Figure 3 Daily Change in the Slab Curling(Hansen, 2002)

Therefore, IRI values which measured at identical section are different as measured time changes because variations of temperature and humidity cause the curling and warping of the slab.

3. Slab Curling Extraction in Jointed Concrete Pavement.

The power spectrum is a graph that represents the frequency component contained in the random signal, and the 'o' area of an ellipse in Figure 4 represents the amplitude and wavelength of 6 m/cycle for a slab length of 6 m.

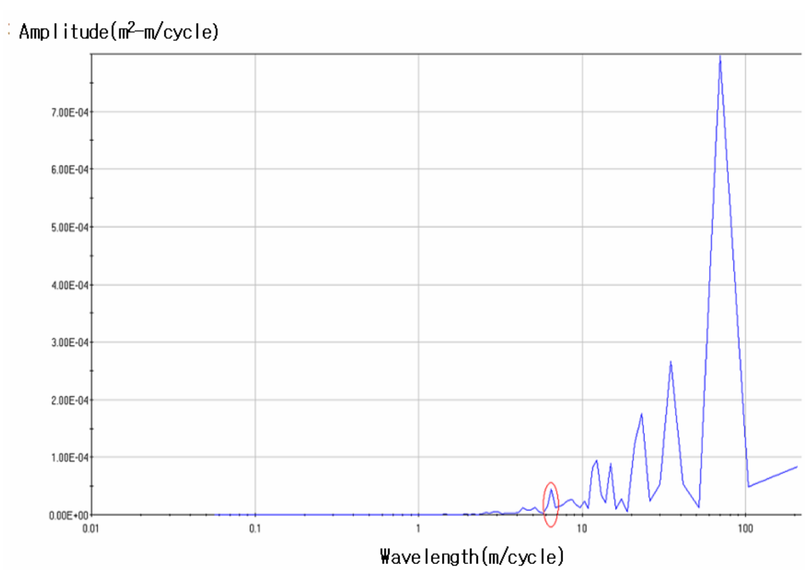

Figure 4 Example of Power Spectrum Analysis

As illustrated in Figure 5, this procedure detects various frequencies using a Power Spectrum Density Analysis that includes measurements of the profile data for the pavement surface. Between each combined frequency, the frequency equivalent to the joint spacing (6m) was removed using a notch filter. It was then restored to the original profile data using the Inverse Fourier Transform. In this way, the IRI was again calculated with the reconstructed profile data. The frequencies appear to be equivalent to the various amplitudes, while the waves belong to the pavement profile data.

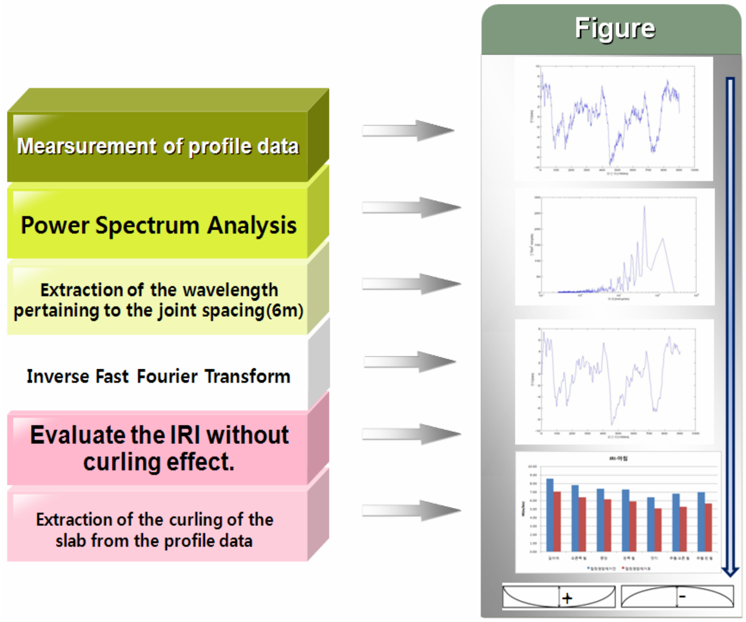

Figure 5 Flow Chart of Slab Curling Extraction Method.(Chon, 2009)

Using these series, the change in the curvature shape of a slab in jointed concrete pavement was analyzed by identifying the wavelength that pertains to the joint spacing of 6 m, which is uniformly used in domestic jointed concrete pavement. Profile data of section that wish to measure curling using the profiler. Calculate the roughness index that exclude curling effect through this remove specification wave using the power spectrum density analysis, fourier transform, inverse fourier transform, illustrated in Figure 5.

3. RELATION IRI AND Curling in the Jung-Bu Expressway Tongyoung-Hanam Section

3.1 Pavement Profile Data Collection and Arrangement

This study collected profile data for the Jung-Bu expressway Tongyoung ~ Hanam concrete pavement section without asphalt concrete pavement. The Jung-Bu expressway contains 4 - 8 lanes, and the details of its construction are given in Table 1. Profile data was collected from each concrete pavement path, which was about 40-60 Km.

Table 1 Investigation Section of Jung-Bu Expressway

Location and Lane	Section	notes
Tongyoung Direction 1 Lane	316~312.96 300~266.49	
Hanam Direction 1 Lane	248.18~250	
Hanam Direction 2 Lane	248.18~310 314~316 329~331.84	

Data for Jung-Bu expressway Hanam direction were acquired as road surface profile data on March 2, 2007. The environmental conditions of that day included a mean air temperature of 8.5℃, a maximum temperature of 10.6℃, and a low temperature of 6.9℃. For long extracts, the curling effect in the original profile is longer, and thus the reliability is low. Therefore, slab curling extraction method estimates employ the mean slab curling value of the whole section. There is an imperfection in that we do not consider the

effect of curling to behave differently according to different environmental conditions that exist in the section being measurement. Accordingly, the data for each section were divided by 160m, and tests were executed for each set of division section profile data.

3.2 Effect Relation between IRI and CURLING

The Jung-Bu expressway Hanam sections are illustrated in Table 2. The influence of the roughness index for total curling in four sections is 0.1-0.27 km, which is 5.2-17.8%, as illustrated in Table 2.

Table 2 IRI of Hanam Direction cruising Lane

Section	IRI Difference (m/Km)	IRI Decreasing rate (%)
1_255_260	0.1~0.21	6.2~15.8
1_260_265	0.1~0.29	7.6~13.5
1_265_270	0.1~0.24	5.2~13.8
1_270_275	0.18~0.27	7.5~17.8

The results from the Jung-Bu expressway Hanam sections are shown in Table 3 The roughness index effect due to curling is 0.1-0.31 km in 5 sections, and this represents a decreasing rate of 4.6-15.4%, as reported in Table 12. This result is a little lower than that obtained for the pathing lane of the same section.

Table 3 IRI of Hanam Direction pathing Lane

Section	IRI Difference (m/Km)	IRI Decreasing rate (%)
248.18_250	0.12-0.14	5.6-7.2
275_280	0.1-0.24	5.8-13.3
270_275	0.13~0.31	6.8~14.0
300_305	0.1~0.25	4.6~15.4
314_315	0.12~0.15	5.7~7.5
315_316	0.15~0.21	10.3~15.0

Table 4 reports the results obtained for the Jung-Bu expressway Tong-Young sections. The roughness index effect in response to the curling effect is 0.1-0.36m/km in six sections, representing a decreasing rate of 3.6-23.4%. This result shows that the roughness index difference of decrease rate is greater than the road section in the Hanam direction. This verifies the presence of a division in the curling effect.

Table 4 IRI of Tongyoung Direction Cruising Lane

Section	IRI Difference (m/Km)	IRI Decreasing rate (%)
275-270	0.09-0.31	3.9-17.2
1_285_280	0.1~0.32	5.3~18.4
1_290_285	0.16~0.39	9.1~21.8
1_295_290	0.19~0.36	12.9~23.4
1_300_295	0.1~0.18	6.3~13.5
1_315_312.96	0.1~0.18	3.6~11.3
1_316_315	0.11~0.2	5.7~10.2

This study verified that curling has some relationship to decreases in the roughness index in the Jung-Bu expressway Tong-young and Hanam Sections. Curling is compared with the roughness index difference on three occasions for the Tongyoung section, Hanam section, and the two sections together. It confirms that the roughness index is affected as the curling magnitude increases, as illustrated in Figure 58. It

exerts an effect of about 0.1 m/km on the roughness index if the curling magnitude is 0.5 mm.

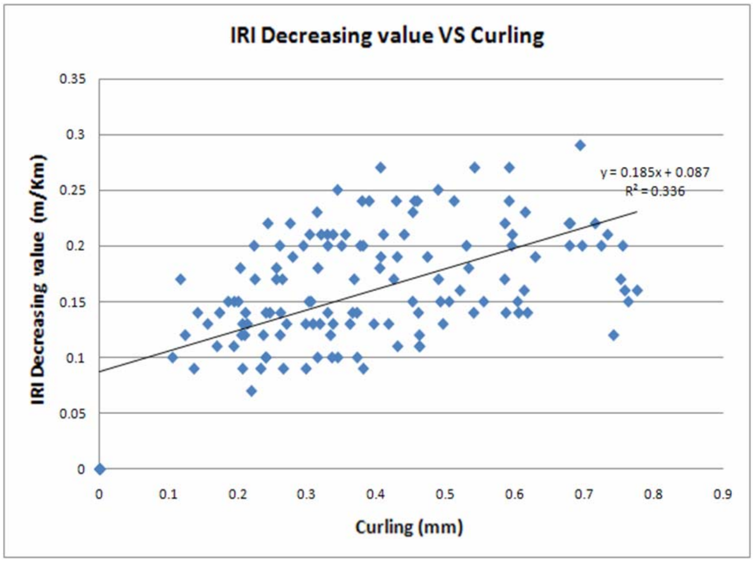

Figure 4 Curling vs IRI Decreasing Rate of Jung-Bu Expressway Hanam Section

Similarly to the Hanam section, the Tong-Young section results confirm that the roughness index changes the increases in the curling magnitude, as illustrated in Figure 58 and 59. In this section, it exerts an effect of approximately 0.15 m/km on the roughness index if we assume the curling magnitude to be 0.5 mm.

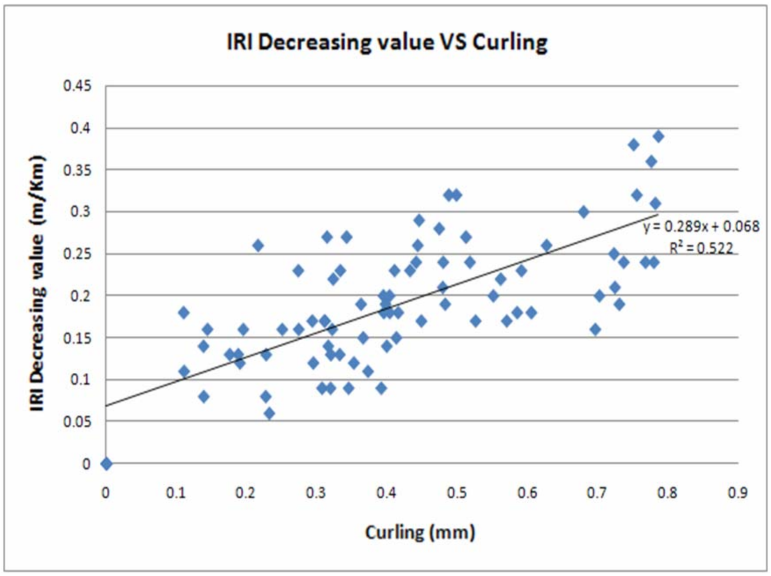

Figure 5 Curling vs IRI Decreasing Rate of Jung-Bu Expressway Tongyoung Section

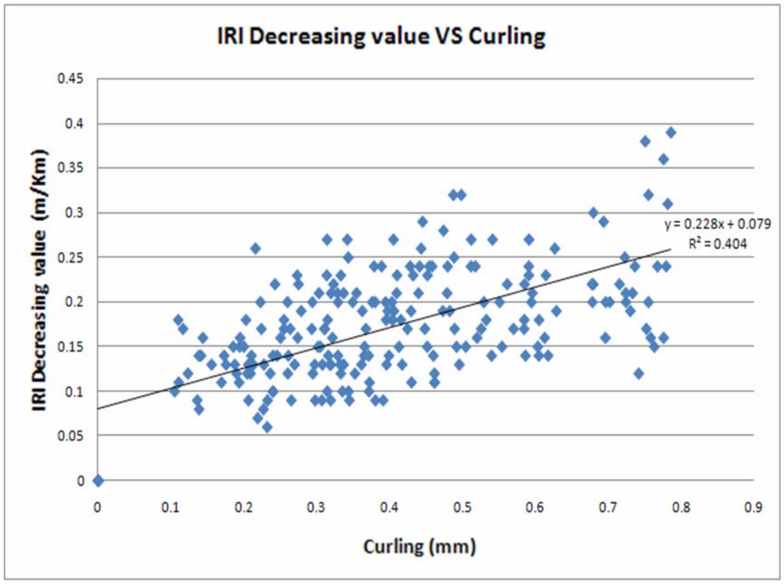

Figure 6 Curling vs IRI Decreasing Rate of Jung-Bu Expressway Hanam and Tongyoung Section

Decrease value of IRI vs Curling magnitude Relation is y = 0.228 * x + 0.079, R^2=0.404 by analogy to the linear relationship of the whole Hanam-Tongyoung section, as illustrated in Figure 60. It confirms that the roughness index is affected as curling increases. In this section, it exerts an effect of approximately 0.11 m/km on the roughness index if we assume that the curling magnitude to be 0.5 mm.

4. CONCLUSIONS

The Joint Concrete Pavement roughness index is affected in the same section by the curling behavior as well as by the environmental load (temperature and humidity). Curling extraction must be carried out prior to calculating the roughness index, which considers the effect of curling. However, the curling measurement must be established at the beginning of construction. We applied the Power Spectrum Analysis, Fourier Transform, and Inverse Fourier Transform techniques to the profile data, which were easily obtained from the field, in order to extract the curling.

The result of the analysis for the Tongyoung-Hanam of the Jung-Bu Expressway

- The IRI decreasing range due to the effect of curling is 0.09~0.27 m/Km about 5.2~17.8% that of the Cruising lane of the Hanam on the Jung-Bu expressway
- The IRI decreasing range due to the curling effect is 0.09~0.31 m/Km about 4.6~15.4% that of the Pathing lane of the Hanam on the Jung-Bu expressway. It suffers less impact than the Cruising lane.
- The IRI decreasing range due to the effect of curling is 0.06~0.36 m/Km about 3.6~23.4% that obtained for the Tongyoung on the Jung-Bu expressway. It is impacted more than the Hanam site.
- For Hanam and Tongyoung, the relationship between curling and the IRI is y = 0.228x + 0.079 R^2= 0.404, which confirms that the effect on the IRI increases as curling increases.

This study evaluate the realistic roughness of the road while considering the curling behavior in the concrete pavement. Thus, this technique was used to analyze the relationship between the roughness index and curling. In this study, the IRI that does not consider the estimated curling provides measurements that are about 3.6 % ~ 23.4%. In additional, Based on the results obtained in the present study, the methods presented herein are interpreted as a little more reliable than slab curling when studying curling and its impact on the roughness index.

5. Acknowledgement

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